

## **Light Yield for Different Cell Geometries And Different Fiber Configurations**

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### **ABSTRACT**

I present results for light yields from extrusion cells filled with liquid scintillator with different geometries. The simulations are based on one of the main features of the baseline detector, ie a looped fiber with both ends coupled to an APD. Besides the cell dimensions, I also vary number of fibers, 1 or 2 looped ones, their diameter, and their positions in the cell. These calculations are based on a modified version of a program originally written by Keith Ruddick. An effort has been made to adjust the relevant parameters to recent experimental data taken by the Minnesota MINOS group.

### **Introduction.**

The purpose of this note is to summarize the results of some simulations performed to investigate various fiber/cell configurations for a possible liquid scintillator detector. Such simulations are useful in guiding initial design of the detector but one should emphasize that for final design one will need experimental verification of the calculated performances. In these simulations I have used a modified version of a program written originally for MINOS by Keith Ruddick. I have also used the recent data taken by Leon Mualen to adjust the relevant parameters in the program. Some of the results presented here have been obtained before and there are no qualitative surprises here.

### **General procedure.**

We assume that the charged particles are incident normally on the scintillator cell, parallel to the assumed beam direction and uniformly distributed along the transverse dimension of the cell. Thus the light yield quoted, calculated for different longitudinal positions in the cell, is for full cell traversal at normal incidence. The fiber is assumed to be looped so that the photons emitted into the “away hemisphere” also reach the APD but with a longer path. The program assumes that the scintillator light is emitted isotropically and uniformly along the path of the incident particle. Individual photons are then traced and their direction determines whether they will hit initially one of the fibers or the internal wall of the cell. They have a finite probability of being absorbed in the liquid during this traversal.

If they hit a fiber, there are 3 possibilities: reflection, transmission, or absorption. If they are absorbed, the resultant green photons, also emitted isotropically, can be trapped (by internal reflection) or not. The trapped photons are then propagated to their APD, the direction determined by angle of emission. Along the path they can be absorbed; if they reach the APD, the probability of their generation of the photoelectron is governed by the

APD quantum efficiency at that wavelength. If the blue photon is reflected or transmitted, it is treated subsequently using identical procedure as used for the “virgin” photons.

A photon that hits the wall can be either reflected or absorbed. The reflection is specular, and subsequently the reflected photon in question has the standard choice of options.

### **Parameters.**

The results we obtain are clearly very dependent on the values of the multiple parameters that enter into the simulation. I want to summarize next briefly the values used and, where appropriate, the rationale for the numbers adopted. Most of the parameters are due to Keith Ruddick and are based either on manufacturers’ specifications or Minnesota group measurements.

Absorption length of green fiber. The numbers adopted for these calculations are partially based on the transmission measurements performed recently by Leon Mualen. Those data were fitted to a double exponential with attenuation lengths of 320 and 1050 cm and 50% apportionment to each component in the initial intensity. The longer length is an approximation to bulk attenuation of the longer wavelengths. The shorter one represents a parametrization of wavelength dependent absorption at shorter wavelengths as well as of the relatively quick absorption of photons emitted at larger angles.

Keith’s program assumes attenuation dependence given by

$$1 / \square_T = 1 / \square_S + 1 / \square_B$$

where the first term corresponds to wavelength dependent absorption and the second to the bulk absorption. The value of  $\square_S$  has wavelength dependence and is based on Bicon data and Minnesota measurements. The finite angle effect is taken care of automatically in the program by correcting the distance along the fiber by the reciprocal of cosine of the emission angle (wrt the fiber axis). For  $\square_B$  we use 13.5 m which is the value that reproduces Leon’s effective attenuation length of 1050 cm. The difference between the two is due to finite angle with respect to the fiber axis; I find that at 15 m still about 25% of the photons have  $|\cos\theta| < 0.75$ .

Blue light transmission. The program uses wavelength dependent transmission measurements by Dave Anderson between 400 and 444 nm. Below that the transmission is taken to be zero, above 444 nm it is taken to be unity.

Emission spectra. The scintillator values come from the Minnesota measurements; the WLS green light spectrum used is the K27 spectrum.

Reflectivity from PVC. The values used in the program come from Minnesota measurements on reflectivity of TiO<sub>2</sub> doped PVC. Above 500 nm it is taken to be 0.966. This is an important number from the point of view of eventual photoelectron yield since the mean number of reflections for photons that eventually get absorbed in the fiber for the cells of interest is about 12 with a rather long tail.

APD Quantum Efficiency. These numbers come from the Hamamatsu specification sheet.

Absolute light yield normalization. It is hard to calculate this number precisely but it is not very important for our purpose since it does not affect relative comparison of different cell configurations. The following is the basis for the procedure adopted. Incident particles are assumed to lose energy in the scintillator according to the Landau distribution as specified in the original program, with the median energy loss of 2.06

MeV. The number of photons emitted for solid scintillator was taken to be 1 for 130 eV of energy loss, approximately 50% of photon yield of anthracene. I finally multiplied the photon yield by a fudge factor such that the yield was the one claimed by Ken Heller for the far end (15 m) of a 3 by 4 cm cell, namely 55 pe. The fudge factor turns out to be 0.6. This appears to be somewhat high for the ratio of liquid to scintillator yield per unit mass and it may well be that Ken's number was somewhat optimistic, specifically in extrapolating from MINOS cell to the postulated cell. In my simulations I found that in the region of cell depth of 3-4 cm, the photoelectron increase, when one increases the cell along the beam direction, is only 60% of photon yield increase, the main loss occurring in the reflections as a typical traversal will have a lower probability of intercepting a photon.

### **Simulation Results.**

I have focused these calculations on two cell configurations: 3.9 x 2.6 cm, current baseline design dimensions and 3.8 x 4.5 cm, suggested cell size for the Totally Active Scintillator Detector (TASD). The first dimension is transverse to the beam, the second one in the beam direction. The cell lengths for the two configurations were 14.6 m and 17.5 m respectively. I have considered considerations with only one looped fiber and two (thinner) looped fibers. For each number of fibers I also looked at 4 different configurations, corresponding to different fiber locations. For single fibers the "Corner" configuration has the two segments of the fiber 1 mm from the walls at diagonally opposite corners. In "uniform" configuration the two segments are at the center vertically and one quarter of the cell width from the vertical sides. In "Near by" configuration they are at one corner next to each other. Finally, in the "Center" configuration they are in the center vertically and separated by a fifth of the cell width. The two fiber arrangements are logical modifications of these configurations. The configurations are illustrated schematically in Fig.1.

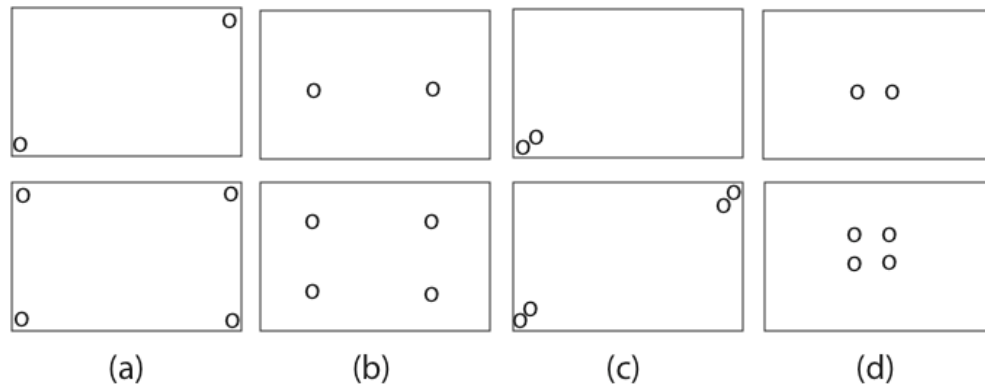


Fig.1 The 8 fiber configurations simulated for this note. From (a) to (d) they are corner, uniform, near by, and center configurations using the terminology defined in the text

The results of the simulations are summarized in Table I for the baseline design cell, and in Table II for the TASD cell. The simulation statistical error on N<sub>pe</sub> for the near end is about 1%, 1.5 % for the far end.

No fibers	Fiber diameter	Configuration	N <sub>pe</sub> at z=0.5 m	N <sub>pe</sub> at z=z <sub>end</sub>	N <sub>refl</sub>
1	0.8 mm	Corner	178.4	57.1	11.8
1	0.8 mm	Uniform	200.4	64.4	10.8
1	0.8 mm	Near by	169.0	54.6	12.9
1	0.8 mm	Center	199.9	64.5	11.0
2	0.5 mm	Corner	184.0	59.3	11.3
2	0.5 mm	Uniform	197.3	63.1	10.7
2	0.5 mm	Near by	180.3	54.6	12.2
2	0.5 mm	Center	200.1	64.4	10.6

Table I. Simulation results for the baseline design cell of dimensions 3.9 x 2.6 cm. Z<sub>end</sub> corresponds to the loop position, 14.6 m from the ends. All the values given correspond to average values. N<sub>refl</sub> is the average number of reflections from the walls before the photon hits a fiber.

No fibers	Fiber diameter	Configuration	N <sub>pe</sub> at z=0.5 m	N <sub>pe</sub> at z=z <sub>end</sub>	N <sub>refl</sub>
1	0.8 mm	Corner	240.4	57.8	12.5
1	0.8 mm	Uniform	265.9	63.5	11.6
1	0.8 mm	Near by	228.6	57.3	13.4
1	0.8 mm	Center	269.7	65.9	11.7
2	0.5 mm	Corner	245.8	60.4	12.2
2	0.5 mm	Uniform	265.8	65.3	11.4
2	0.5 mm	Near by	228.6	59.4	13.0
2	0.5 mm	Center	274.7	67.6	11.3

Table II. Results of the simulations for the TASD cell, 3.8 x 4.5 cm and 17.5 m long.

### **Discussion of results.**

The light yields for the configurations considered here do not differ greatly from each other. This is partly due to the fact that the depth of the T ASD cell was chosen to give comparable light yields from the far end as the baseline design cell.

It appears that two 0.5 mm fibers give very similar yield as one 0.8 mm diameter fiber. The cost of the former configuration, however, should be about 22% cheaper if one assumes that the fiber costs scale with the volume of the fiber. The similarity of the light yield means that, for the parameters used in this simulation, we are no longer in the “large diameter” regime where light yield scales linearly with the radius.

There is some gain, at the level of 10-15% if the fibers are away from the corners of the cell. Thus it appears worthwhile to investigate how difficult it would be to impose such a constraint during the module assembly process.

Finally I want to repeat an obvious, but nevertheless a very important comment, that the results presented here are highly dependent on the assumptions regarding the optical parameters used, especially wall reflectivity and the wavelength dependence of the absorption length of the WLS fiber used. Thus experimental verification of these parameters, both at the component and systems level, is essential before one can draw final conclusions regarding optimum configuration.

### **Acknowledgements**

I want to thank Keith Ruddick for making his program available and Leon Mualen for sending me the raw data on his light attenuation measurements.